# A GEOLOGIC OVERVIEW OF THE WILD RIVERS RECREATION AREA, NEW MEXICO

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**Abstract**—The U.S. Bureau of Land Management's (BLM) Wild Rivers Recreation Area sits at the junction of the Rio Grande and Red River in north-central New Mexico. The 26-million-year history of the Rio Grande rift serves as a framework to discuss, in general terms, the rocks and landforms which are exposed in the Recreation Area and vicinity. Early Miocene rift-related rhyolitic volcanism was a precursor to uplift of the Sangre de Cristo Mountains and deposition of Santa Fe Group sediments in the subsiding rift basin. Pliocene volcanism of the Taos plateau, including the Servilleta Basalt flows, and dacite and andesite cones, followed. More recently, the Rio Grande and Red River have cut down through the Taos Plateau to form gorges. This paper concludes with a short overview of the proposed Molycorp, Inc. mill-tailings pond on Guadalupe Mountain and related ground-water and management issues.

## INTRODUCTION

The Wild Rivers Recreation Area is located just west of Questa in north-central New Mexico, about 22 km south of the Colorado border and 18 km north of Taos (Fig. 1). Here, the Red River joins the Rio Grande in a setting of deep canyons carved 250 m down into a high plateau (Fig. 2). The 19,090-acre Recreation Area is on public land maintained by the U.S. Bureau of Land Management (BLM). Facilities include the Arthur W. Zimmerman Visitor Center, an outdoor amphitheater and several campgrounds and picnic areas on the rims of, and within, the canyons. Numerous trails connect canyon and rim. Piñon-juniper and ponderosa-pine woodlands and sagebrush steppes harbor abundant wildlife, including hawks, eagles, deer and coyotes. A corridor along the river is included in the Rio Grande Wild and Scenic River, which was designated by Congress in 1968 as a protected area. This article summarizes previous geologic studies in and near the Recreation Area, in simpler, less technical terms. The history of the Rio Grande rift provides a timeline which serves as a framework for this story.

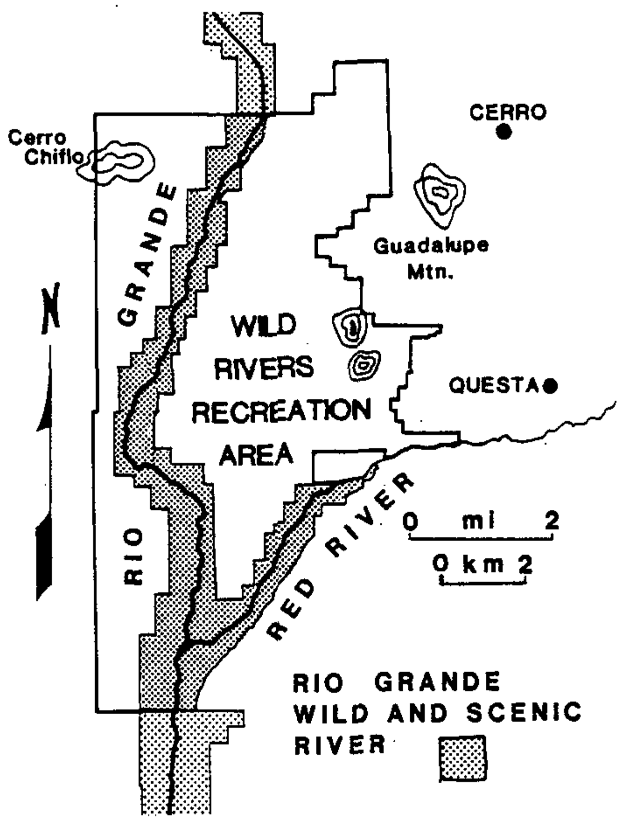


FIGURE 1. General location of Wild Rivers Recreation Area (from BLM Wild Rivers Management Plan, 1988).

## GEOLOGIC SETTING

The Rio Grande rift is the key to understanding the geology of the Recreation Area, for the types of rocks and landforms here are a result of the rift. A rift is a long, narrow region where the crust of the earth is cracking along faults and pulling apart. As the crust pulls apart, tilted blocks subside along the faults to form valleys and hills in the central part of the rift. Mountain blocks, also broken by faults, rise along the margins of the rift. Hot melted rock from deep inside the earth squeezes up along the cracks and faults, and upon reaching the surface, erupts to form volcanoes. Streams erode mud, sand and gravel from the mountains and deposit these sediments in the rift valleys. There are many cycles of subsidence, erosion and eruption, so the rift valley contains alternating layers of sedimentary and volcanic rocks.

The Rio Grande flows south down the Rio Grande rift, through a series of long, narrow offset basins, from near Del Norte in Colorado to El Paso in Texas, bisecting the state of New Mexico (Fig. 3). The Recreation Area is located in the San Luis basin portion of the rift. The San Luis basin extends from south of Taos, New Mexico, to north of Alamosa, Colorado, and is bounded on the east by the Sangre de Cristo Mountains and on the west by the Brazos uplift and the San Juan Mountains. South of the Colorado border, the cones of the Taos Plateau volcanic field are scattered through the middle of the valley. The gorges of the Rio Grande and Red River were formed by erosion and are not the sides of the rift. The geologic map in Figure 4 locates features in the Recreation Area which are mentioned in this article.

## GEOLOGIC HISTORY

### Early rift history

The Rio Grande rift began to form in northern New Mexico (Chapin, 1979, 1988) about 26 to 28 million years ago (Ma). Volcanic activity occurred for several million years before this, but it was related to the San Juan Mountains volcanic field in Colorado and to volcanoes in the mountains north of Taos. The rift follows a zone of weakness in the earth's crust dating from mountain-building events millions of years before rifting (Baldridge and Olsen, 1989). When the rift first began to form, the mountains that rimmed the rift were low, and the river and gorge as we know it today did not exist. Faults were mainly in a NNW-SSE direction. Many of the first volcanoes along the rift were made of silica-rich rhyolite. These rhyolitic volcanoes were explosive and spewed ash and debris over wide areas. After erupting, some of these volcanoes and the areas surrounding them collapsed, forming large depressions called calderas (Baltz, 1978; Lipman and Mehnert, 1979).

The eastern half of one of these early Miocene volcanic calderas (the 16 Ma Questa caldera) is preserved on the flanks of the Sangre de Cristo

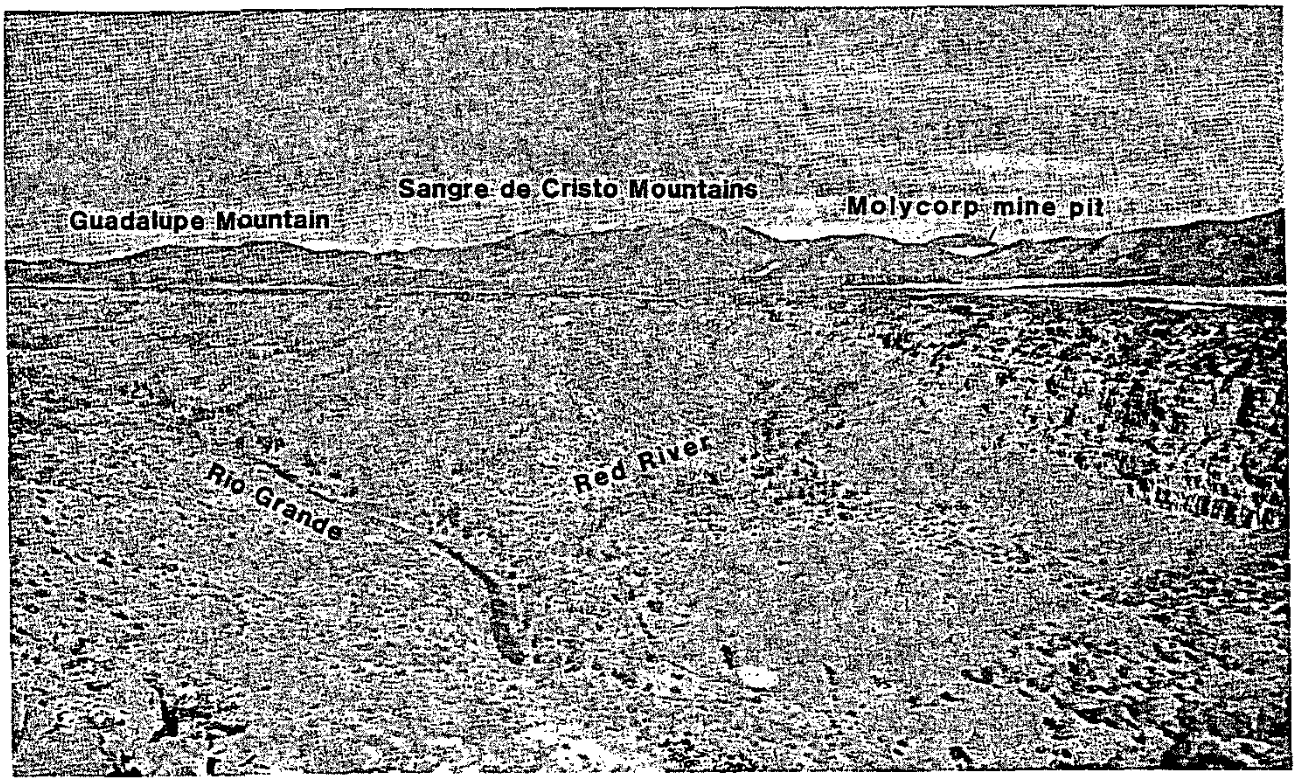


FIGURE 2. Wild Rivers Recreation Area, view northeast. The Red River flows from the Sangre de Cristo Mountains towards the center of the picture, where it joins the Rio Grande, which flows from the upper left. The Molycorp molybdenum mine dumps are on the flanks of the Sangre de Cristo Mountains in the upper right corner.

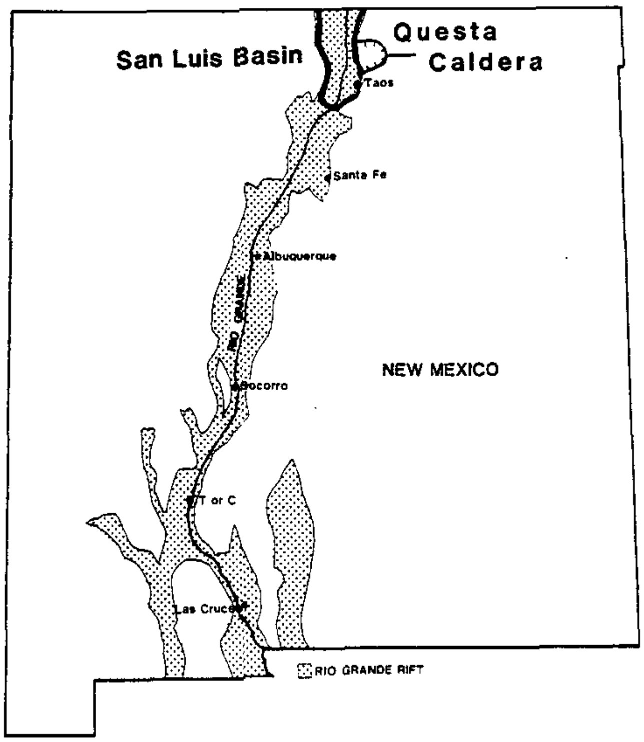


FIGURE 3. Diagram of Rio Grande rift basins in New Mexico. The San Luis basin is the northernmost segment of the rift in New Mexico.

Mountains east of the Recreation Area (Lipman et al., 1986; Johnson et al., 1989). This is the site of the Molycorp molybdenum mine. Volcanic activity after the caldera formed (about 23 Ma) caused hot waters, rich in dissolved metals such as molybdenum, to circulate. As the waters cooled, the metals were deposited in cracks and spaces in the rock. The western half of the caldera is faulted down and buried beneath younger rocks in the rift valley. The caldera explosion blasted debris over a wide area of what is now the San Luis basin. These hot rock, pumice, glass and crystal shards welded together to create a rock layer called the Amalia Tuff. Outcrops of this tuff have been found up to 45 km southwest of the caldera, in the Tusas Mountains (Lipman et al., 1986). The Amalia Tuff forms two low hills about 5 km west of the visitor center, just east of Brushy Mountain (Dungan et al., 1989).

The rhyolitic rock that forms Brushy Mountain, 6 km west of the visitor center, represents another volcano that formed about 22 Ma and has since been worn down. This was the site of the Silbrico perlite quarry, which operated intermittently from around 1960–1987. Perlite is a form of volcanic glass which greatly expands when heated, very much as popcorn does. The perlite was shipped by truck to the railhead at Antonito, Colorado, and from there to processing plants in the eastern United States. The main use of the perlite was as a lightweight additive to roofing material.

Between 20 and 10 Ma volcanic activity in the rift lessened. Faulting caused the rift to deepen, and sediments were shed from the mountains along the edges of the rift into the basin. At first the sediments had many volcanic fragments because the early volcanoes were eroding. These sediments are called the Los Pinos Formation along the west side of the San Luis basin. About 10 Ma, the rift began to deepen at an increased rate and the San Luis Basin tilted to the east. The direction of faulting changed from NNW-SSE to N-S, and the Sangre de Cristo Mountains lifted farther above the rift on the east side. This exposed Precambrian granitic rocks, which were eroded and shed into the basin.

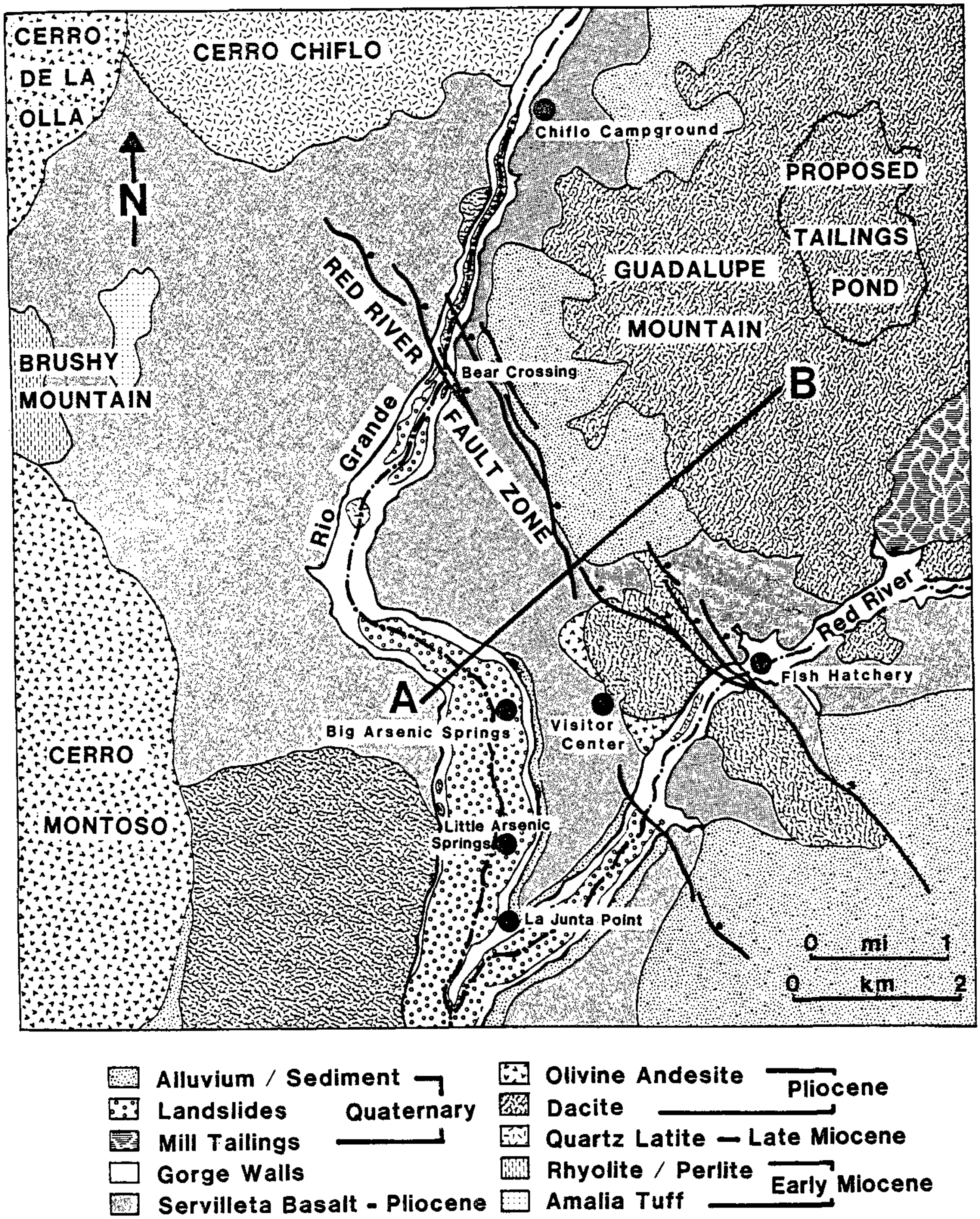


FIGURE 4. Geologic map of the Recreation Area and vicinity (modified from Wells et al., 1987). A-B is location of cross section shown in Figure 8.

These sediments, composed mostly of granitic rock fragments, are known as the Santa Fe Group. They were laid down as alluvial fans and lake, stream and dune deposits at the foot of the mountains (Baldridge and Olsen, 1989).

About 10 Ma, in late Miocene time, volcanic eruptions formed Cerro Chiflo, a mountain of quartz-latite rock which stands above the western rim of the present-day gorge, 8 km north of the visitor center. This fine-grained rock is dotted with larger whitish crystals of plagioclase feldspar. If one looks across the gorge from Chiflo Campground, one can see wavy bands on the cliffside which are internal flow bands in the quartz latite.

The tip of another quartz-latite volcano, dating from this time, is exposed along the western wall of the Rio Grande gorge 5 km south of Cerro Chiflo. This cone was buried by younger sediments and volcanic flows but was exposed again when the river cut the gorge (Dungan et al., 1984; Johnson et al., 1989). From 10 to 5 Ma, volcanic activity slackened, but sediments of the Santa Fe Group continued to fill the deepening rift.

### Taos Plateau volcanic field

About 5 Ma, in Pliocene time, volcanic activity began to increase again. Volcanoes erupted along a wide belt, known as the Jemez lineament, which extends from southwestern to northeastern New Mexico. Our study area is located just north of where the lineament intersects the rift. For the next 3 million years many kinds of volcanic rocks were erupted from at least 35 vents and cones in what is now called the Taos Plateau volcanic field (Lipman and Mehnert, 1979). Different volcanic vents had many eruptions over thousands or millions of years, so that flows coming from different sources at different times overlapped with one another. The flows also interfingered with sediments from alluvial fans which were deposited between volcanic eruptions.

Some of the first eruptions in the volcanic field were of dacite, a fine-grained rock rich in silica and peppered with larger dark pyroxene crystals. Guadalupe Mountain, just north and east of the visitor center, began to form about 5 Ma and continued to erupt on occasion over the next two million years. The dacite flows coming from Guadalupe Mountain splay out like fingers of a hand. Where these fingers intersect the gorge, such as 1 to 2 km south of Cerro Chiflo, they are "chopped off" into oval cross sections as much as 50 to 100 m in diameter along the gorge walls. These pods display concentric cracks around the edges, like layers of an onion (Dungan et al., 1984). Another low dacite volcano sits between Cerro Montoso and the Rio Grande gorge, directly opposite La Junta Point. Flows from this dacite are exposed in the gorge walls above the middle layer of Servilleta Basalt. This dacite is so fine grained that the local Indians used it instead of obsidian as their major source of material for stone points and tools (Dungan et al., 1989). San Antonio Mountain (3 Ma) and Ute Mountain, west and north of the Recreation Area, are also dacite cones.

The Servilleta Basalt is the most widespread type of rock in the Taos Plateau volcanic field. It was erupted in three main pulses between 3.6 and 4.5 Ma (Lipman and Mehnert, 1979). Basalt lava has more iron and magnesium and less silica, making it flow more easily than the viscous dacite lavas. Instead of piling up as a steep cone, the basalts spread out as thin flows over hundreds of square kilometers across the rift, covering or lapping at the bases of older volcanoes, such as at the south end of Cerro Chiflo. The basalt flows overlap with layers of sediment and with thicker and more viscous flows from dacite volcanoes erupting at the same time. The source of the basalt appears to be several low, broad volcanoes 16 to 25 km west and northwest of the visitor center.

As you hike down the gorge from the rim (Fig. 5), you can see two main groups of Servilleta Basalt flows which form cliffs along the upper walls of the gorge. Between and below the flows are poorly cemented layers of silt, sand and gravel from alluvial fans and other sedimentary deposits in the Santa Fe Group. The upper cliff is the upper Servilleta Basalt layer. It is separated by 10 to 30 m of sediment from a lower cliff, which comprises the middle and lower Servilleta Basalt layers. There is little or no sediment between the middle and lower layers

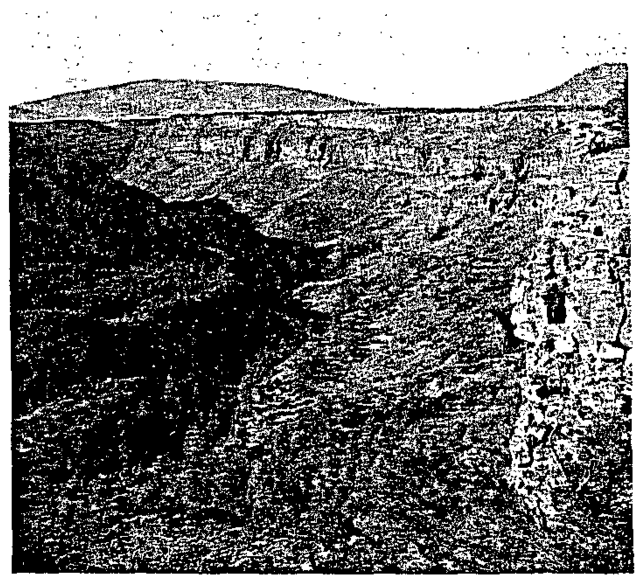

FIGURE 5. View north from near La Junta Point. The two main layers of Servilleta Basalt are visible on the east wall of the gorge; the upper layer forms the cliff in the foreground. Early Miocene rift-related rocks of Brushy Mountain are exposed in the two low hills on the left above the gorge. Behind them on the middle horizon is Cerro de la Olla, a 2.3 Ma olivine andesite shield volcano. Cerro Chiflo, a late Miocene quartz-latite dome, is on the horizon at the right.

(Dungan et al., 1984). Commonly the sediments at the base of individual flows are reddish in color. When the molten lava that today is solid basalt spread over the land, it baked the ground underneath, which formed red iron oxide. In many areas the basalt displays columnar joints. These cracks were created when the basalt shrunk while it was cooling. In places the basalt is highly vesicular (full of round holes). These were formed by pockets of gas trapped in the lava when it cooled and hardened.

Starting about the time the Servilleta Basalt stopped erupting and continuing for the next million years or more, several large volcanoes of andesite rock, rich in green olivine crystals the size of a grain of rice, formed above the basalt layers. These andesitic volcanoes include Cerro de la Olla (2.3 Ma), which is the large cone 13 km northwest of the visitor center, and Cerro Montoso, 8 km west of the center. Olivine andesite is also exposed in the walls of the Red River gorge about 4 km east of the Rio Grande junction. Here, the andesite overlies the middle layer of Servilleta Basalt, and the upper layer is missing. This andesite erupted from low vents northwest and southeast of the fish hatchery. Northeast of this volcano, drill holes have penetrated lake sediments, which may indicate that the volcano dammed the ancestral Red River (Dungan et al., 1989). Various types of lavas continued to erupt until 1.8 Ma, when volcanic activity ended, and the Taos Plateau volcanic field became basically what we see today.

### Recent rift history

During the past 1.8 Ma, much uplift and erosion (but no volcanic activity) has occurred near the Recreation Area. Uplift of much of northern New Mexico caused the ancestral Rio Grande to extend its drainage basin to the north by capturing and connecting older drainage basins in the rift (Baltz, 1978). The Taos plateau continued tilting to the east, causing sediments washed down from the Sangre de Cristo Mountains to form large fans which covered the Servilleta Basalt in the eastern half of the rift. The present-day course of the Rio Grande follows the western edge of these fans. To a large extent, the location of the river was controlled by where the west-dipping fans thinned out against the east-dipping Servilleta Basalt.

The rift is still active today. Faults along the west side of the Sangre de Cristo Mountains near the Colorado border have lifted layers of

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Servilleta Basalt from 250 to 600 m up to the east within the last 4 Ma, and topographic benches along the mountain front to the south show as much as 900 m of offset within the same time period. Some of these faults show low scarps created by earthquakes within the last 10,000 years (Menges, 1987b). Nearer the Recreation Area, the northwest-trending Red River fault zone crosses the Red River near the fish hatchery, passes 1 km northeast of the visitor center and crosses the Rio Grande gorge at Bear Crossing. Here, the basalt layers on the north side of the fault have dropped about 25 m compared to the south side. The Red River fault may have moved as recently as 20,000 years ago. The fault has been active at least since the volcanic field was formed, because older layers of rock in the Red River gorge are offset more than younger layers (Menges, 1987a). The zone may even be a reactivation of one of the northwest-trending faults in the early rift, or the surface expression of the buried west edge of the Questa caldera (Dames and Moore, unpub. report to Molycorp, Inc., 1988).

Several ice ages, occurring between 2 million and 10,000 years ago, caused glaciers to form high in the Sangre de Cristo Mountains. Streams from the melting glaciers fed water to lake basins which formed in the rift valley. These glacial streams dumped fine silts and clays into the lake basins.

Figure 6 is a cross section across the modern rift from Tres Piedras to Wheeler Peak. Notice that the deepest part of the rift is between the Rio Grande and the Sangre de Cristo Mountains and is filled with a stack of sediments up to 3300 m thick (Muehlberger and Muehlberger, 1982). West of this is an uplifted block, along which older volcanic rocks in the rift, such as at Brushy Mountain, are exposed at the surface.

### Formation of the gorge

Where was the Rio Grande a million years ago? One theory proposed by Wells et al. (1987) is that a large lake covered Sunshine Valley north of Guadalupe Mountain and may have extended up the San Luis Valley into southernmost Colorado (drill holes have penetrated lake sediments in Sunshine Valley). The volcanoes of the Taos Plateau formed a dam on the south side of the lake, blocking any outlet. During this time, the Red River was the headwaters of the Rio Grande because there was no through-going river coming from the north. According to this theory, uplift in the region caused a tributary of the ancestral Rio Grande to start cutting its way back into the volcanic field. About 700,000 years ago, this tributary cut headward through the hills of the Taos Plateau and began to drain the lake. An alternative idea is that the lake rose high enough to spill over through the gap between Cerro Chiflo and Guadalupe Mountain. In either event, the lake water rushed through the new outlet and began to cut a deep and narrow gorge.

Another possibility (E. H. Baltz, written commun., 1988) is that the gorge is present because of subsidence and erosion in the Española basin to the south after the ancestral Rio Grande cut White Rock Canyon northwest of Santa Fe. This rapid change in base level of the Rio Grande initiated nickpoints (steeper slopes) in the river profile that migrated northward with time. The Recreation Area is at such a nickpoint. Figure 7 shows the slope of the Rio Grande from Alamosa, Colorado, on the left to Pilar, New Mexico, on the right. North of Latir Creek, the slope of the river is gentle and the gorge is less than 60 m deep. The river may have been near the level of the old lake basin. However, where the Rio Grande flows through the volcanic hills between Latir Creek and Red River, the slope of the river steepens. The gorge becomes as much as 250 m deep. The river drops 200 m in 20 km, creating Class 6 whitewater rapids. Here, the river is actively cutting down to a lower level. Below the Red River, the slope of the Rio Grande flattens out again, although the canyon remains deep.

The gorge cuts straight across the Red River fault rather than shifting to the southeast or northwest along the fault zone (see Figure 4). The gorge depth increases by 50 m south of the fault, which drops strata to the northeast. The relation of the river to the fault indicates that the Rio Grande started cutting the gorge when there was little or no surface offset, or scarp, along the fault zone, and was able to maintain its course in spite of fault movements. It also suggests that the gorge was formed by headward erosion of the Rio Grande from the south, rather than by outflow from a lake to the north (which would have diverted the Rio Grande southeast along the fault zone).

Erosion in the gorge has caused looser sediments below the basalt cliffs to slump down and form large hummocky landslides. In places, long "stairsteps" of basalt have slipped down from the rim and rotated backwards. On the rim, deep cracks have developed in the basalt several

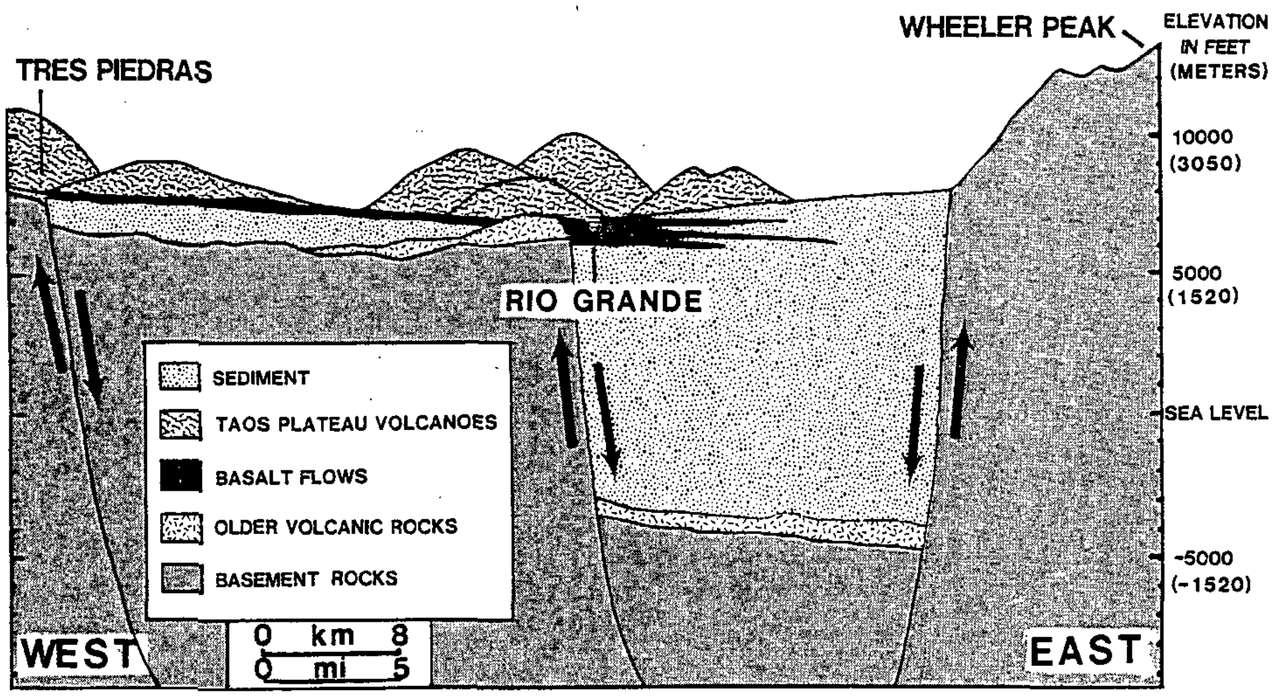


FIGURE 6. Diagrammatic cross section across Rio Grande rift from Tres Piedras to Wheeler Peak (adapted from Muehlberger and Muehlberger, 1982). Vertical exaggeration 5×.

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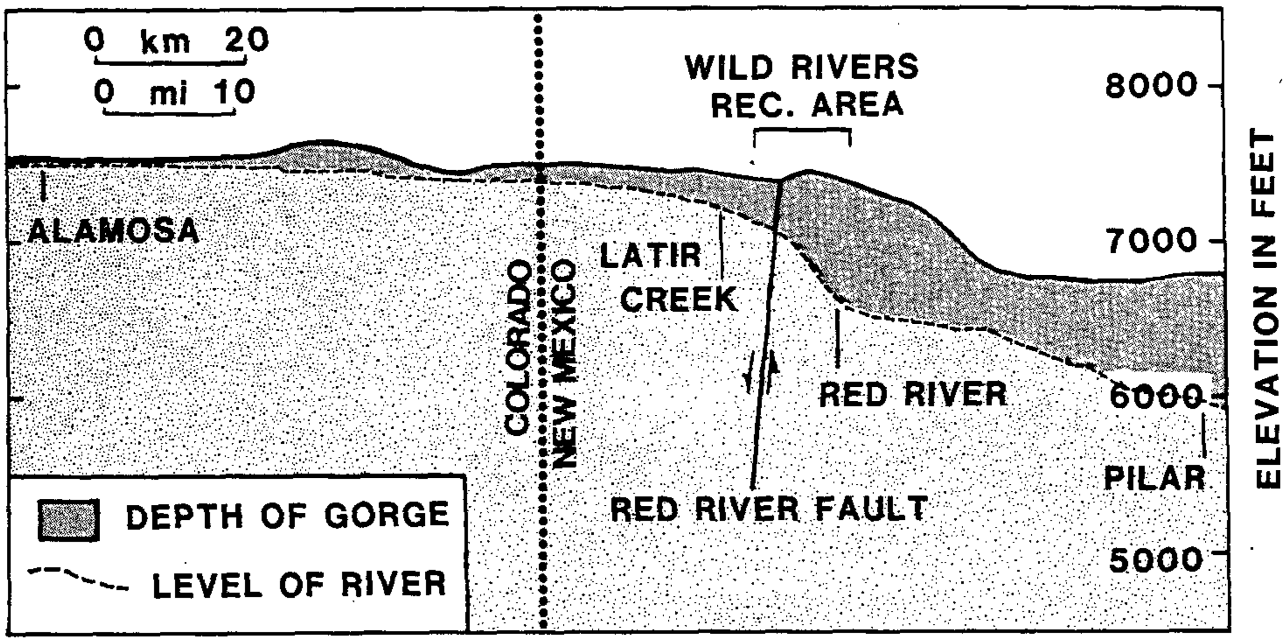


FIGURE 7. Slope of Rio Grande and depth of Rio Grande gorge from Alamosa, Colorado to Pilar, New Mexico (adapted from Wells et al., 1987). Vertical exaggeration 12×.

meters to tens of meters in back of and parallel to the gorge walls, and large blocks are tilted at crazy angles, ready to peel off and slide into the gorge. The trail from Little Arsenic Spring goes up one huge landslide all the way to the rim of the gorge.

Figure 8 is a cross section across the Rio Grande gorge and Recreation Area (see line A-B on Figure 4). Landslides cover the lower areas in the gorge. Two groups of Servilleta Basalt flows separated and underlain by Santa Fe Group sediments, all of Pliocene age, are exposed on the gorge walls. To the northeast, these layers overlap with fingers of dacite rock derived from Guadalupe Mountain. The Red River fault zone drops the rock layers down to the northeast.

## CURRENT ISSUES

### Molycorp tailings

Molycorp, Inc. presently operates a molybdenum mining and milling facility east of the town of Questa. Underground mining began in the 1920's. Expansion to open pit operations in 1964 and the construction of a 15,000 ton-per-day mill created the need for tailings disposal. Construction of the existing disposal site west of Questa began in 1964. Since then, tailings slurry has been piped 13 km down the Red River valley from the mill to the disposal area. In 1983, a new underground mine went into operation and the open pit mine was phased out. Currently, about 1.8 km$^2$ (450 acres) of tailings are piled between the southeast edge of Guadalupe Mountain and the town of Questa.

In 1974, Molycorp began a search for a new tailings disposal site to handle excess tailings from the expanded operations. They looked at 23 possible sites and in 1980, narrowed the search to eight sites on which detailed engineering feasibility studies were conducted. The preferred sites were expansion of the existing site and the saddle between the north and south summits of Guadalupe Mountain (Dames and Moore, unpub. report for Molycorp, Inc., 1988).

In 1981, Molycorp filed claim under the General Mining Law of 1872 to 5.3 km$^2$ (1300 acres) on Guadalupe Mountain for a proposed 2.3 km$^2$ (568 acre) tailings pond. These millsite mining claims are on public land managed by the BLM. The 1872 Mining Law gives the claimant the right to pursue operations on federally managed lands as long as it does not cause unnecessary or undue degradation of those lands (Code of Federal Regulations 43 CFR 3809). Molycorp submitted a proposed plan of operations to BLM in 1982. The BLM prepared an Environmental Impact Statement (EIS) on the proposed plan, and issued a Record of Decision (ROD) and permit letter in December of 1989. The permit letter grants Molycorp conditional approval to construct the tailings pond, but requires that Molycorp comply with the environmental protection measures outlined in the EIS and decision document. Also, before construction can begin, Molycorp must obtain: (1) an approved National Pollutant Discharge Elimination System (NPDES) permit from the Environmental Protection Agency; (2) a Groundwater Discharge Permit from the State Environmental Improvement Division (EID); (3) a facility engineering and design permit from the State Engineer; and (4) approval of their Tailings Management Plan from BLM. They must also establish an air and water quality monitoring system to ensure that discharges do not exceed state standards, and post a $6000 per acre reclamation bond. In January 1990, the Sierra Club Legal Defense Fund appealed BLM's decision to the Department of Interior Board of Land Appeals (IBLA), possibly delaying the project.

### Ground water

The controversy over where to put mill tailings from the Molycorp molybdenum mine has generated several studies of ground water under the Recreation Area and vicinity. The studies have tried to determine where, how much and how fast ground water flows underneath the area and how seepage from mill tailings might affect water quality.

Although the volcanic rocks themselves are dense, their fractures transmit large amounts of ground water. Water moves through porous rubble zones at the bases of individual Servilleta Basalt flows and through columnar joints which crack the dense interior of the flows. In places, springs and seeps discharge from the base of the basalt (C. M. Menges, unpub. report for New Mexico Environmental Improvement Division, 1984). The dacite "fingers" transmit water mainly through concentric cracks near their edges; their interiors are fairly impermeable. The source of Big Arsenic Springs is thought to be water discharging from a finger of dacite which extends west from Guadalupe Mountain to the Rio Grande gorge. The dacite lava followed and filled an ancient valley cut into less permeable Santa Fe Group sediments several tens of meters below the Servilleta Basalt (Dames and Moore, unpub. report for Molycorp, Inc., 1988).

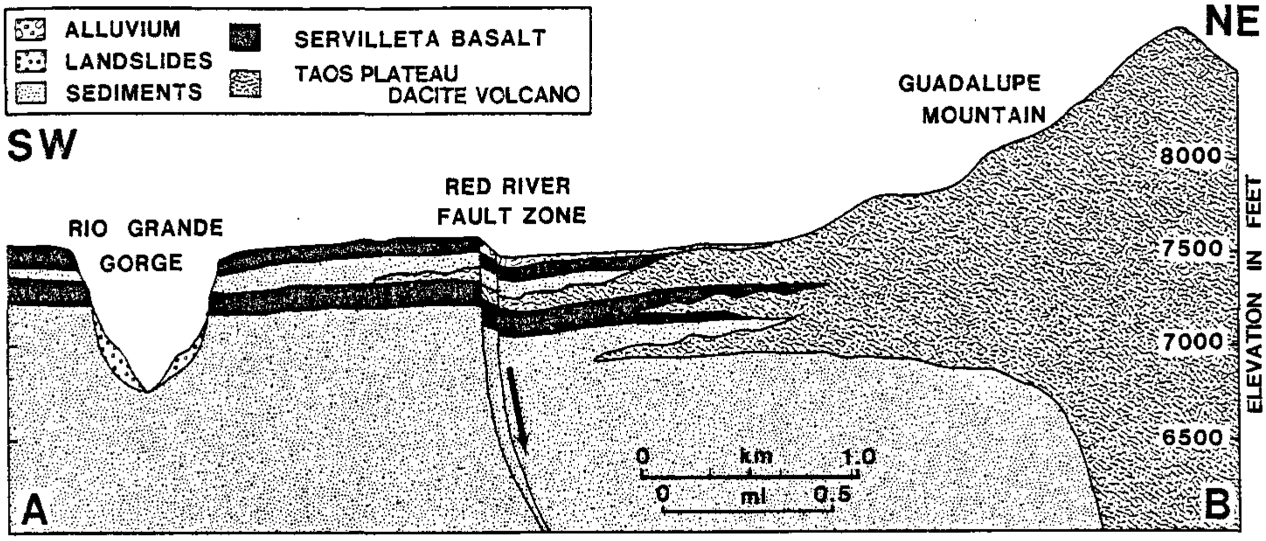


FIGURE 8. Geologic cross section A-B across Rio Grande gorge 4 km north of Rio Grande–Red River junction (modified from Menges, unpub. 1988). View northwest. See Figure 4 for location of cross section. Vertical exaggeration 3×.

The sediments of the Santa Fe Group are mainly fine-grained sand or silt, with some gravel in a silty matrix. These sediments retard the flow of ground water more than the volcanic rocks. The landslides in the gorge transmit water underground from the base of the volcanic rocks to near river level, where the water discharges at places like Little Arsenic Springs (C. M. Menges, unpub. report for New Mexico Environmental Improvement Division, 1984).

Several hydrologic test wells as much as 360 m deep were drilled by Dames and Moore (unpub. reports for Molycorp, Inc., 1986, 1988) near Guadalupe Mountain. Depth to ground water near the proposed mill tailings facility was about 240 m below the surface. The wells encountered alternating layers of andesite/dacite, basalt, breccia, scoria, cinders, paleosols, welded tuff and rhyolite. The deeper layers, especially the cinders and some of the breccias, were highly fractured and showed a high potential for ground water flow. A substantial amount of ground water flows under the proposed site. The groundwater gradient was about 40 m per km, and the hydraulic conductivity was calculated as 740 m per day. An average ground-water flux of at least 1.5 $m^3$ per second occurs across an 8 km distance along a line from Cerro Chiflo to the head of the Red River canyon (BLM Draft Environmental Impact Statement (EIS), 1988). Although average ground-water quality in the area was better than the maximum allowable concentration in the New Mexico State ground-water standards, concentrations of some chemicals at certain locations exceeded the standards. On a number of occasions, cadmium and lead levels at the BLM Visitor Center well, and cadmium, lead, iron and manganese levels at Fish Hatchery Spring No. 1 were higher than standards (BLM Draft EIS, 1988).

In general, ground water flows west-southwest through the volcanic and sedimentary rocks, eventually discharging into the Rio Grande and Red River. The Red River fault zone probably deflects this flow to the south. The fault brings permeable, water-bearing volcanic rocks in the downdropped block to the northeast (Fig. 8) side by side with less permeable sediments of the Santa Fe Group in the upthrown block to the southwest (BLM Draft EIS, 1988). Southwest of the fault zone, the water table is generally in the Santa Fe Group sediments below the volcanics, with the exception of the dacite finger which feeds Big Arsenic Springs and a few springs which discharge from the base of the lowermost basalt.

### Management direction

In February 1988, the Taos Resource Area Office of the BLM published a Management Plan for the Wild Rivers Recreation Area. The plan calls for recognizing the rivers and their canyons as the main features to be managed in a natural setting for viewing and interpretation. Interpretive exhibits at the visitor center, including geology, will be updated. The plan recognizes that mineral exploration and development could compromise the natural values of the area, and proposes to withdraw the Recreation Area from mineral entry (such as mining claims, oil and gas leasing, sand and gravel sales, etc.). In December 1989, the BLM officially withdrew about 5000 acres with facilities or improvements from mineral entry. They plan to withdraw the remaining acreage in the Recreation Area during 1990.

The proposed mill tailings site lies outside the Recreation Area, along its eastern border, and is not affected by the withdrawal. The plan calls for quarterly sampling of water quality from wells and from Big and Little Arsenic Springs. The Record of Decision approving the tailings pond also provides several stipulations to mitigate potential impacts to the Recreation Area, including: an air and water quality monitoring system; tailings pond and dam revegetation measures; limitations on removal of existing vegetation; tailings dam contours designed to minimize visual intrusion; and restrictions on vehicle noise and blasting. The BLM operates under the concept of multiple-use management—balancing the interests of many different users of the public lands. Applying this concept to managing the Recreation Area will continue to be a challenge.

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### REFERENCES

Baldridge, W. S. and Olsen, K. H., 1989, The Rio Grande rift: American Scientist, v. 77, pp. 240–247.

Baltz, E. H., 1978, Resume of the Rio Grande depression in north-central New Mexico; *in* Hawley, J. W., ed., Guidebook to the Rio Grande rift: New Mexico Bureau of Mines and Mineral Resources, Circular 163, pp. 210–228.

Chapin, C. E., 1979, Evolution of the Rio Grande rift: a summary; *in* Reicker,

R. E., ed., Rio Grande rift—tectonics and magmatism: American Geophysical Union, Washington, D.C., pp. 1–5.

Chapin, C. E., 1988, Axial basins of the northern and central Rio Grande rift; *in* Sloss, L. L., ed., Sedimentary cover—North American craton—U.S.: Geological Society of America, The geology of North America, v. D-2, pp. 165–170.

Dungan, M. A., Muehlberger, W. R., Leininger, L., Peterson, C., McMillan, N. J., Gunn, G., Lindstrom, M. and Haskin, L., 1984, Volcanic and sedimentary stratigraphy of the Rio Grande gorge and the late Cenozoic geologic evolution of the southern San Luis Valley: New Mexico Geological Society, Guidebook 35, pp. 157–170.

Dungan, M. A., Thompson, R. A. and Stormer, J. S., 1989, Excursion 18B: Rio Grande rift volcanism: northeastern Jemez zone, New Mexico; *in* Chapin, C. E. and Zidek, J., eds., Field excursions to volcanic terranes in the western United States, Volume I: Southern Rocky Mountain region: New Mexico Bureau of Mines and Mineral Resources, Memoir 46, pp. 435–486.

Johnson, C. M., Shannon, J. R. and Fridrich, C. J., 1989, Excursion 15B: Roots of ignimbrite calderas: Batholithic plutonism, volcanism, and mineralization in the southern Rocky Mountains, Colorado and New Mexico; *in* Chapin, C. E. and Zidek, J., eds., Field excursions to volcanic terranes in the western United States, Volume I: Southern Rocky Mountain region: New Mexico Bureau of Mines and Mineral Resources, Memoir 46, pp. 275–302.

Lipman, P. W. and Mehnert, H. H., 1979, The Taos Plateau volcanic field, northern Rio Grande rift, New Mexico; *in* Reicker, R. E., ed., Rio Grande rift—tectonics and magmatism: American Geophysical Union, Washington, D.C., pp. 289–311.

Lipman, P. W., Mehnert, H. H. and Naeser, C. W., 1986, Evolution of the Latir volcanic field, northern New Mexico, and its relation to the Rio Grande rift, as indicated by potassium-argon and fission track dating: Journal of Geophysical Research, v. 91, pp. 6329–6345.

Menges, C. M., 1987a, Stratigraphic and morphologic evidence for recurrent Pliocene-Quaternary activity along the Red River fault zone; *in* Menges, C. M., Enzel, Y. and Harrison, B., eds., Quaternary tectonics, landform evolution, soil chronologies and glacial deposits—northern Rio Grande rift of New Mexico: Friends of the Pleistocene, Rocky Mountain Cell Guidebook, pp. 205–206.

Menges, C. M., 1987b, Temporal and spatial segmentation of Plio-Quaternary fault rupture along the base of the western Sangre de Cristo mountain front; *in* Menges, C. M., Enzel, Y. and Harrison, B., eds., Quaternary tectonics, landform evolution, soil chronologies and glacial deposits—northern Rio Grande rift of New Mexico: Friends of the Pleistocene, Rocky Mountain Cell Guidebook, pp. 71–94.

Muehlberger, W. R. and Muehlberger, S., 1982, Española-Chama-Taos: a climb through time: Socorro, New Mexico Bureau of Mines and Mineral Resources, Scenic Trips to the Geologic Past No. 13, 99 pp.

U.S. Bureau of Land Management, 1988, Draft Environmental Impact Statement, Molycorp Guadalupe Mountain tailings disposal facility: Contract publication by ERT, Fort Collins, Colorado, for BLM Albuquerque District, New Mexico, 184 pp.

U.S. Bureau of Land Management, 1989, Record of Decision—Molycorp Guadalupe Mountain tailings disposal facility: Publication of BLM Albuquerque District, New Mexico, 7 pp.

U.S. Bureau of Land Management, 1988, Wild Rivers Recreation Area management plan: Publication of BLM Taos Resource Area, Albuquerque District, New Mexico, 58 pp.

Wells, S. G., Kelson, K. I. and Menges, C. M., 1987, Quaternary evolution of fluvial systems in the northern Rio Grande rift, New Mexico and Colorado; *in* Menges, C. M., Enzel, Y. and Harrison, B., eds., Quaternary tectonics, landform evolution, soil chronologies and glacial deposits—northern Rio Grande rift of New Mexico: Friends of the Pleistocene, Rocky Mountain Cell Guidebook, pp. 55–70.